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Use

# A DATA STORAGE SYSTEM FOR OBTAINING MISSILE REENTRY HEATING DATA

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## Summary

A miniature data storage system used to obtain missile reentry heating data is described. The system does not employ a radio link. Instead, digital information is stored in a 360-bit non-destructive readout ferrite memory which is interrogated after recovery of the instrument package. The stored digital information is a series of times at which predetermined nose-cap temperatures were reached.

## Introduction

The Langley Research Center of NASA is currently planning a series of reentry materials experiments using solid-propellant rockets to obtain speeds in excess of 34,000 feet per second. Originally, it was planned to include no instrumentation in these payloads because of severe weight limitations and to limit the experiment to an examination of the recovered nose cone. Because of the desirability of having supplemental in-flight data, a study was undertaken to determine the lightest and smallest satisfactory instrumentation scheme.

Obtaining data during the reentry of a body into the atmosphere is complicated by the fact that an ionization sheath capable of greatly attenuating radio signals forms around the body. At a reentry velocity of 34,000 feet per second, all frequencies between VHF and X-band are unsatisfactory for real-time telemetry. An alternate to real-time telemetry is the use of a buffer storage system which accepts data during reentry and is read out repeatedly through a radio link after the blackout period.

After studying the use of real-time telemetry at microwave frequencies and buffer storage with subsequent transmission at VHF, it was concluded that the use of a miniature ferrite memory system with no radio transmission link provided the best solution. Instrumentation weight would be minimized by eliminating the need for a transmitter, batteries to power the transmitter, and an antenna system. The memory would accept data during reentry and be interrogated after recovery of the nose cone. The slight additional payload weight with its attendant reduction in reentry velocity was more than offset by the value of the additional data.

## Design Objectives

The trajectory of a typical materials experiment flight is shown in figure 1. The vehicle is a five-stage Scout which achieves a maximum speed of 34,900 feet per second just prior to

reentry. After reentry the instrument package separates from the fifth-stage motor, and a parachute slows its descent. Two VHF "Sarah" beacons in the instrument package facilitate its recovery from the ocean. Because of the high levels of shock and vibration during launch and the rapid decelerations during reentry and impact, the instrument package must be extremely rugged.

The data of interest are a series of six temperature histories at six different depths in the ablative nose cap. Figure 2 shows a prediction of these histories. It would be desirable to record the leading edge of these histories up to the time of burn off in the case of the forward stations and up to the point of inflection in the case of the remaining stations. The most logical temperature sensor is a thermocouple, but the attendant low-level multiplexing and amplification problems made this sensor appear impractical from the standpoint of payload weight. The sensor chosen is a 0.014-inch-diameter bead thermistor. This thermistor may be used to measure temperatures up to 550° C, but repeatability is poor above 300° C. For this reason, temperature measurements were restricted to the range of 50° C to 260° C. Although the forward stations reach temperatures far exceeding 260° C, it is felt that their histories may be accurately extrapolated from data below 260° C.

Instead of determining the six temperature histories in the conventional manner by recording temperatures at known times, the times at which predetermined temperatures are reached are recorded in a ferrite memory. This data format makes it possible to greatly reduce memory capacity without loss of information. In each case, the predetermined temperatures are 50° C, 100° C, 150° C, 200° C, and 260° C. Figure 2 shows data points at the temperatures of interest superimposed on the expected heating curves.

## Sensors

The major criteria in choosing a particular thermistor were maximum operating temperature, repeatability, small physical size, and rapid transient response. It was important that the thermistor not only be statically accurate but that it also contribute as little dynamic error as possible to the temperature measurement by virtue of its presence. A group of thermistors was repeatedly temperature cycled between 25° C and 260° C to establish accuracy and repeatability. These tests proved that once calibrated the chosen thermistors were stable well within 1 percent throughout the operating temperature range. The transient response of several units was evaluated by rapidly submerging them in a liquid epoxy resin

at 150° C while monitoring the resistance change with an oscilloscope. Rise times to 63 percent of steady-state temperature were in the order of 50 ms which was adequate for the proposed heating rate experiments. The conclusion drawn from the testing program was that a 0.014-inch glass-coated bead thermistor was quite suitable and required less complex signal conditioning circuitry than a thermocouple. The penalty in using a thermistor is an upper limit in operating temperature of 260° C.

Figure 3 shows the integration of a thermistor into a sensor plug. A cylindrical plug of the ablation material used in the nose cap first has grooves cut in its face and sides. Next the thermistor is installed flush with the forward face of the plug and bonded in place with DEN-438 epoxy. After this, two #30 stranded wires are high-temperature soldered to the thermistor leads and likewise bonded to the plug. The entire unit is calibrated and finally installed in the nose cap by pressing it into a hole of accurately known depth.

#### System Description

A block diagram of the entire system is shown in figure 4. The 360-bit memory is organized into 30 words of 12 bits each with each word representing the time of a different temperature event. Multiaperture cores are employed as a precaution against accidental loss of the data during readout. All readout circuitry is constructed as auxiliary ground equipment in order to conserve weight and completely isolate the read and write circuitry.

The 12 bits of time information stored as each predetermined temperature is reached are obtained from a flip-flop time register driven from a crystal clock. The basic clock frequency of 100 kc is divided by 4096 in 12 counter stages in order to provide the time register with one pulse every 41 ms. These pulses are counted in the time register which is capable of representing any time within a 167.8-second data period to a quantization accuracy of plus or minus 20.5 ms.

The programmer starts the counting sequence when it receives a pulse just prior to launch through the payload umbilical. For approximately the first 400 seconds of the flight the programmer, using the time register as an input, inhibits operation of the memory. About 400 seconds after launch and 20 seconds before reentry the programmer resets the time register to zero and enables the memory and temperature detector circuits. For the next 167.8 seconds data may be recorded in the memory in any sequence. Afterwards the memory is again inhibited and the current driver power supply is shut off as a safety precaution against accidental writing.

Six separate temperature detectors accept signals from the six thermistors. The outputs of each temperature detector appear on five lines,

one corresponding to each temperature. As each temperature of interest is reached, a pulse appears on the corresponding line, actuating a word current driver. Simultaneously, bit current drivers corresponding to "ones" in the time register are enabled. Bit current drivers corresponding to "zeros" in the time register remain off. The half currents generated by the word and bit current drivers sum to duplicate in the memory whatever word appeared in the time register when the temperature event occurred. It should be noted that it is possible to store up to six words simultaneously with each one corresponding to a different temperature detector.

The system requires a total of 900 milliwatts which is supplied by a mercury battery power supply. The batteries are capable of operating the system for several hours in order to provide a margin of safety even though the mission will be approximately 10 minutes long.

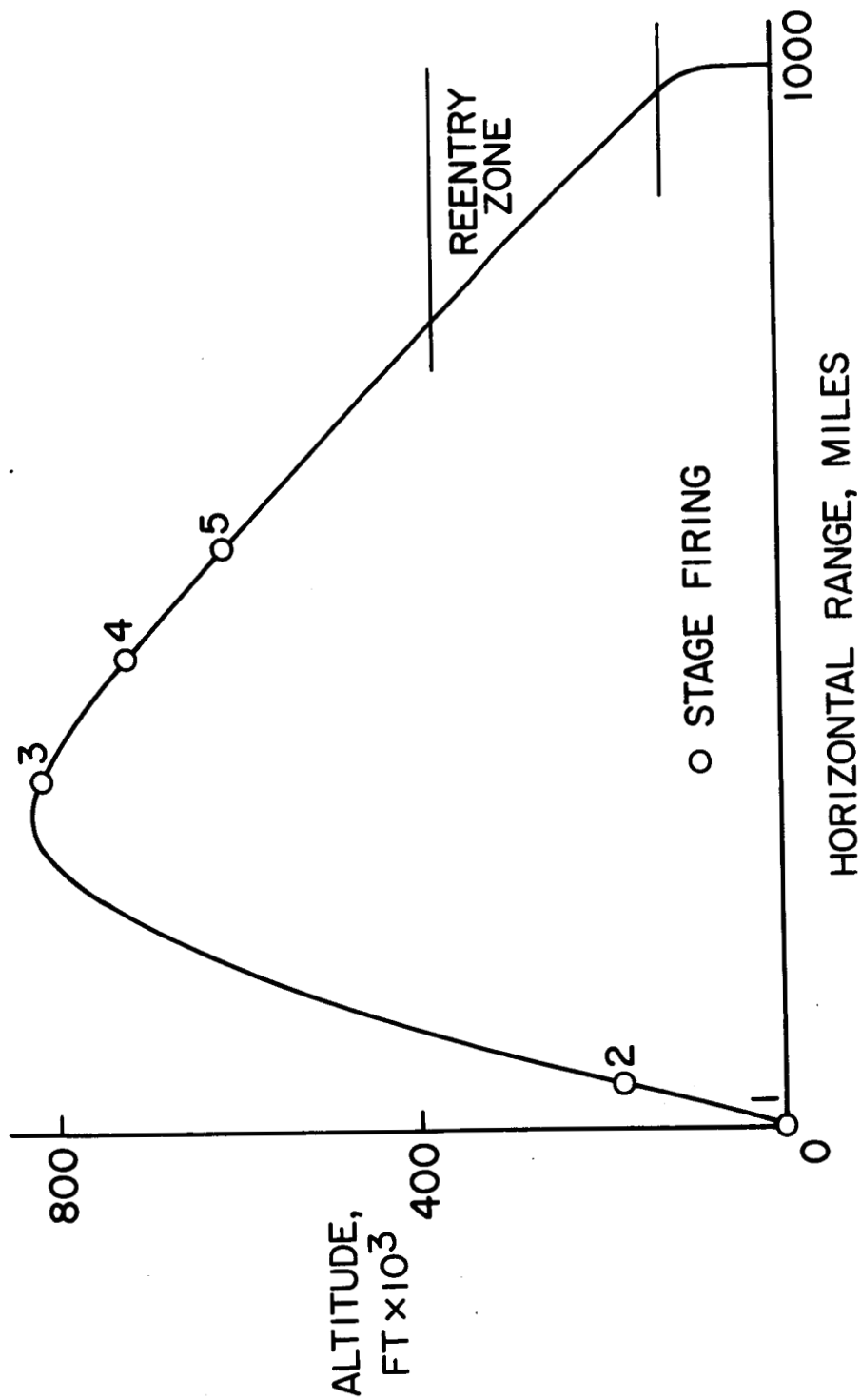
A high degree of redundancy on the subsystem level has been included in this system to enhance reliability. In general, it is possible for one temperature detector or one current driver to fail without affecting operation of the remaining circuits. Also, an internal short circuit in any subsystem will not load the power supply excessively. The only circuits in which failures are almost certain to be catastrophic are the clock, time register, and programmer.

#### Memory Design

As noted previously, the memory plane consists of 360 multiaperture devices in order to provide nondestructive readout. A pictorial representation of four adjacent cores is shown in figure 5. A clear winding threading all memory cores as well as a number of square loop switch cores in the current driver circuits is pulsed through the umbilical prior to launch to place all cores in the "zero" state. Since no circuitry is included in the payload which is capable of duplicating this operation, there is a minimum probability of accidentally clearing the memory. Writing of data is accomplished by simultaneously driving half currents through the word and bit lines threading the major aperture. All 12 bits of a single word are written simultaneously.

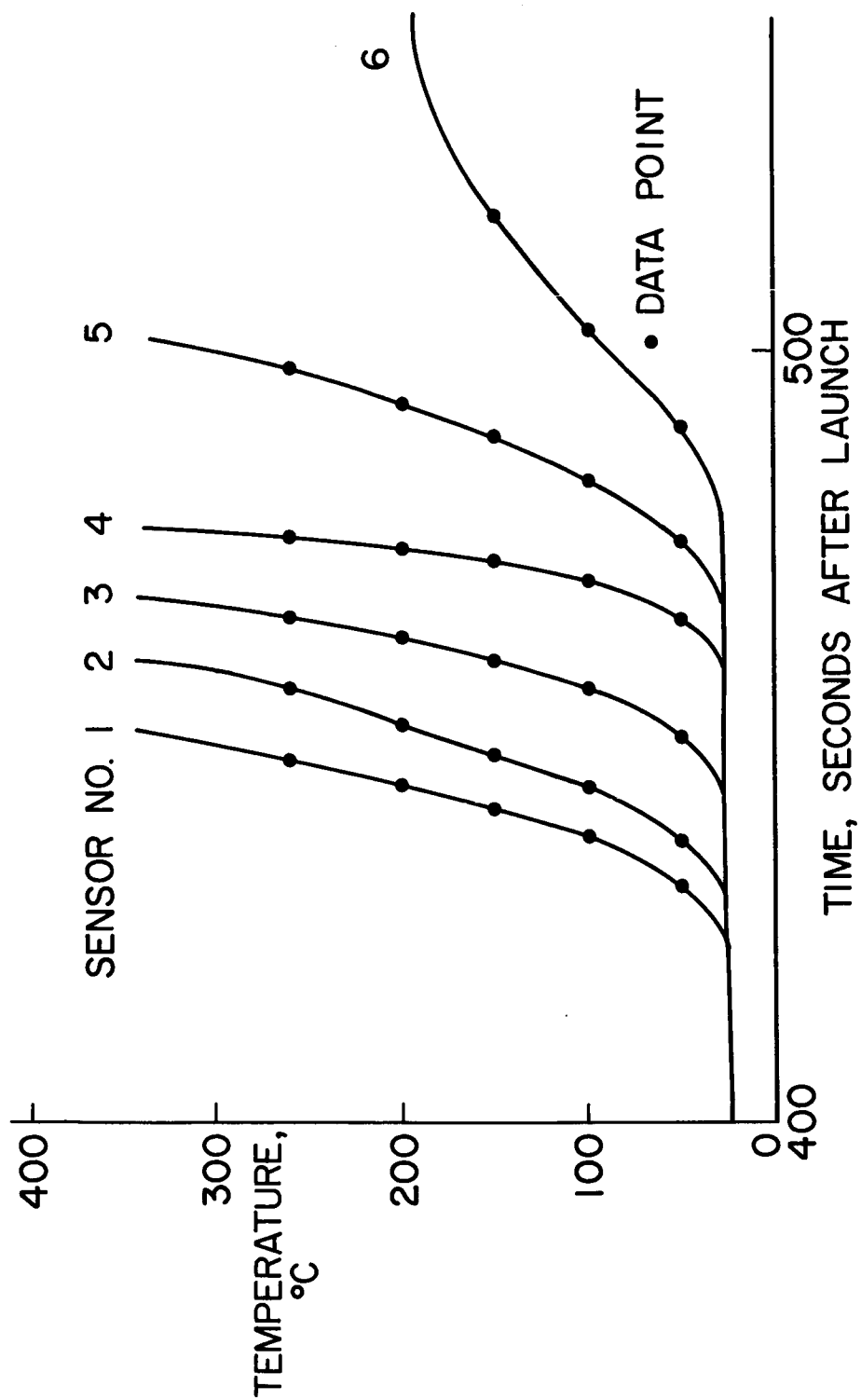
Temperature compensation of memory drive currents is necessary in the operation of this memory since the unit must operate between 0° C and plus 90° C. Compensation is accomplished by providing a low standby drain, regulated power supply having an output voltage dependent on ambient temperature. This power supply regulates the voltage of a bank of capacitors which supply power to all current drivers. The current drivers draw negligible standby current. Whenever a temperature event occurs, the current drivers produce half currents proportional to the capacitor voltage, discharging the capacitors slightly in the process. Subsequently, the capacitors are charged back to the regulated power supply output voltage

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NASA

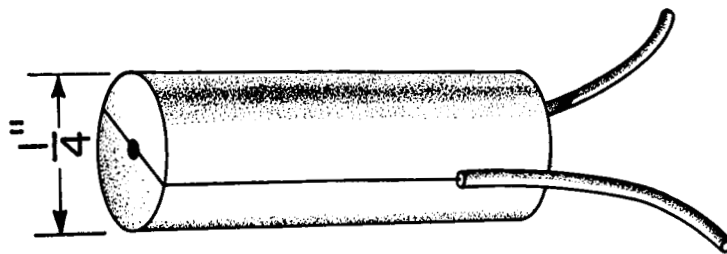
Figure 1.- Scout reentry trajectory.



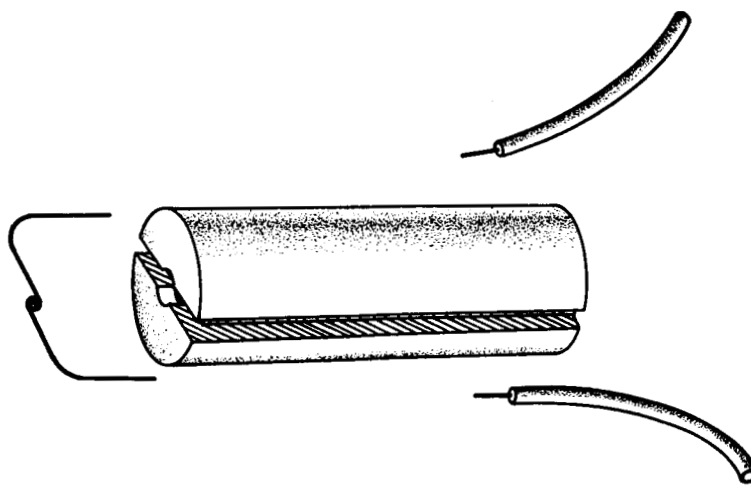
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Figure 2.- Predicted temperature histories.

COMPLETED PLUG

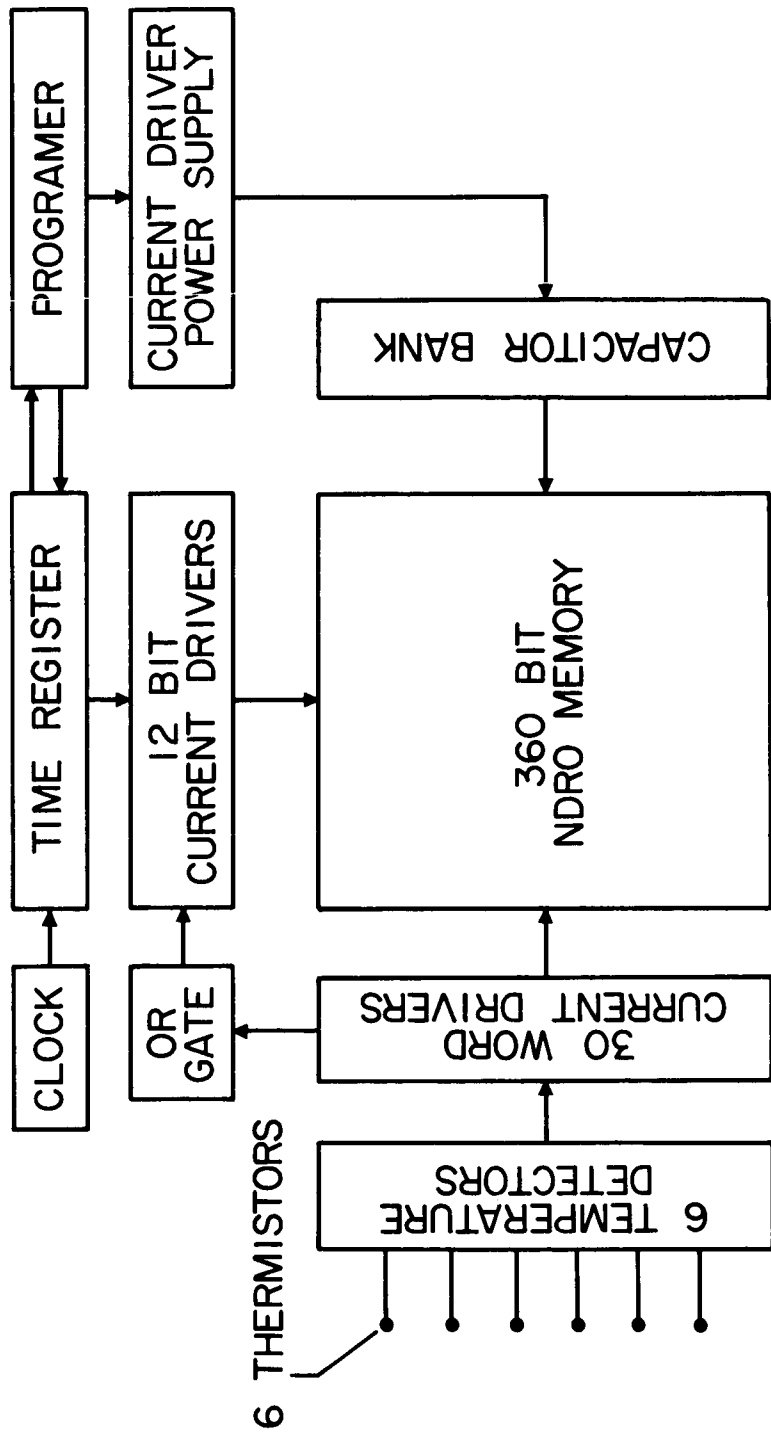


EXPLODED VIEW OF SENSOR  
PLUG



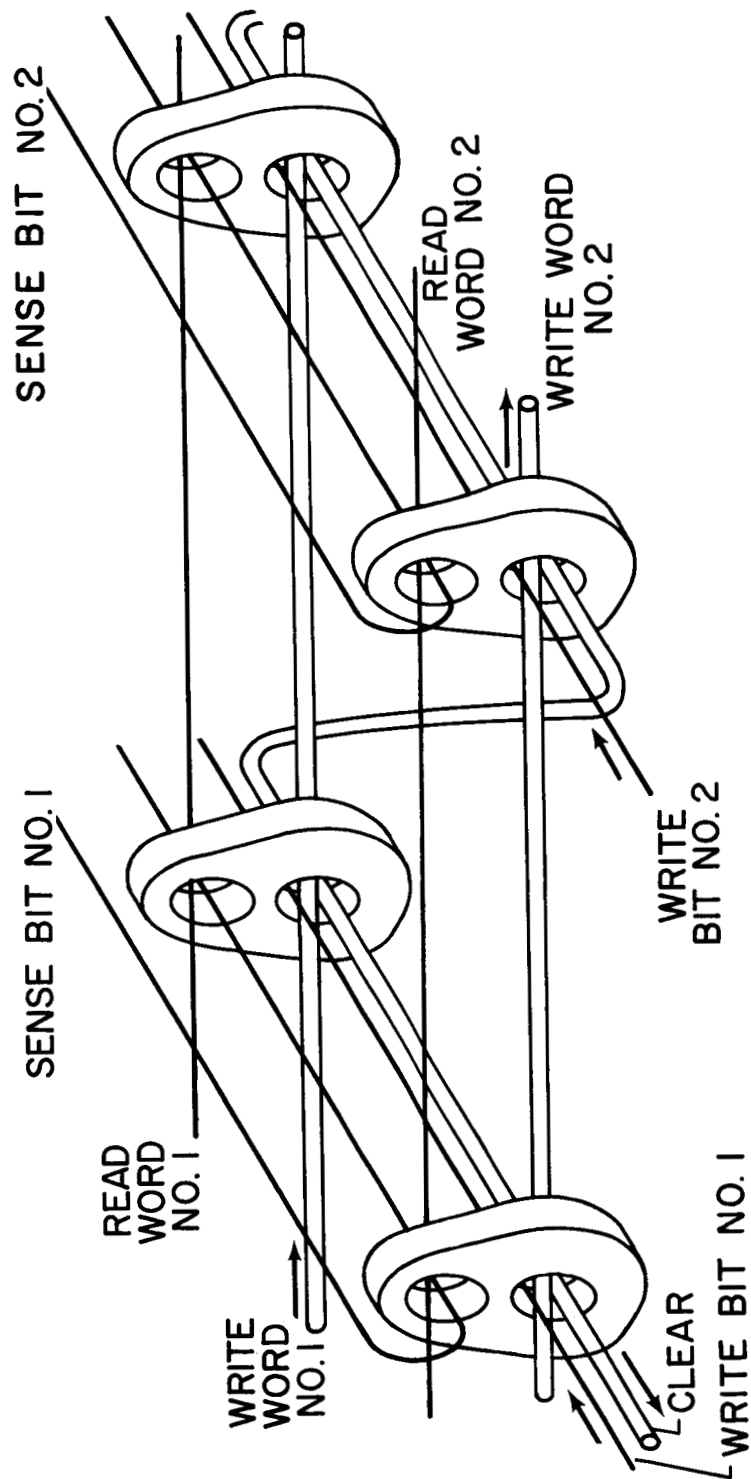
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Figure 3.- Sensor plug construction.



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Figure 4.- Block diagram of system.



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Figure 5.- Memory wiring.



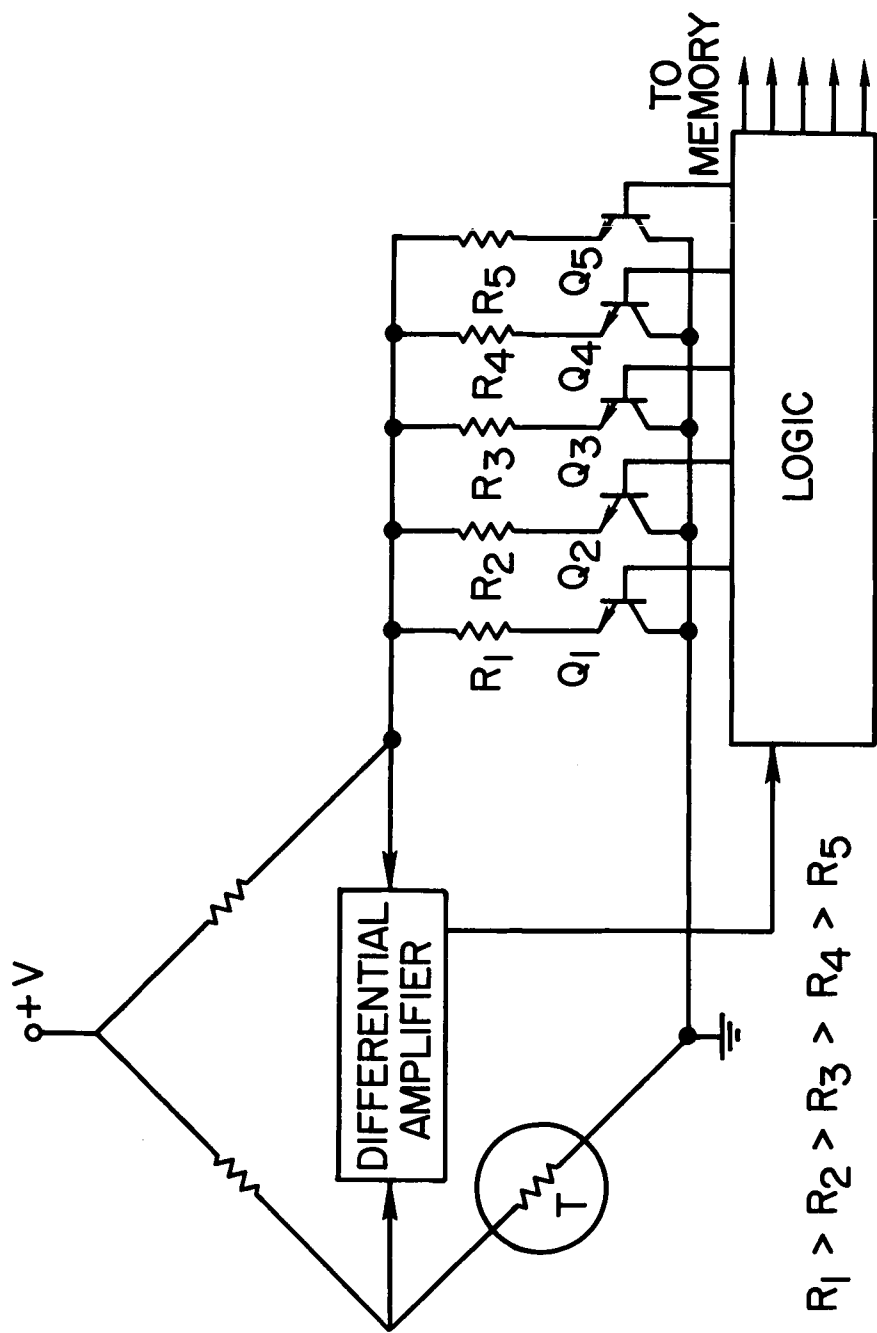
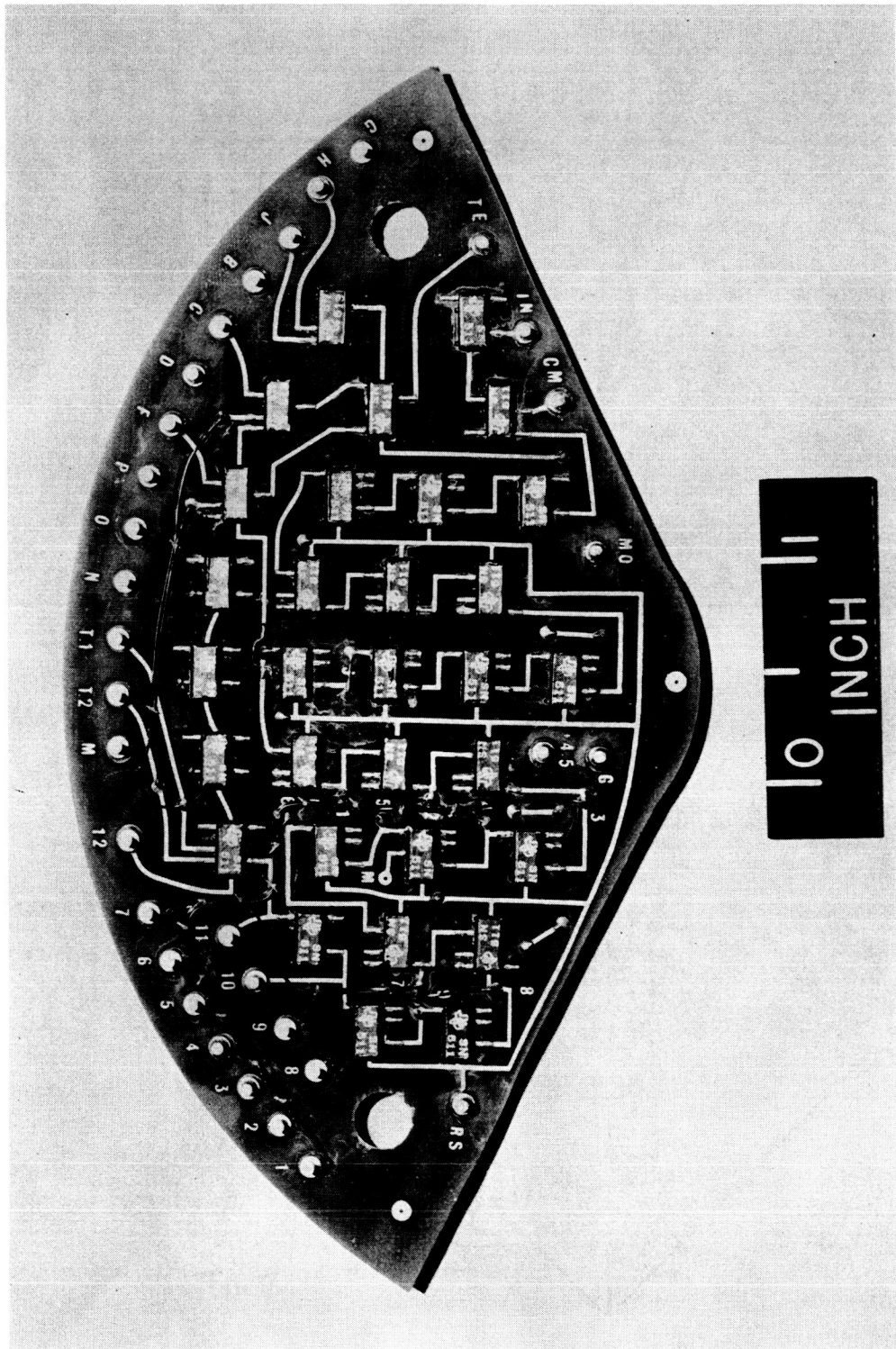
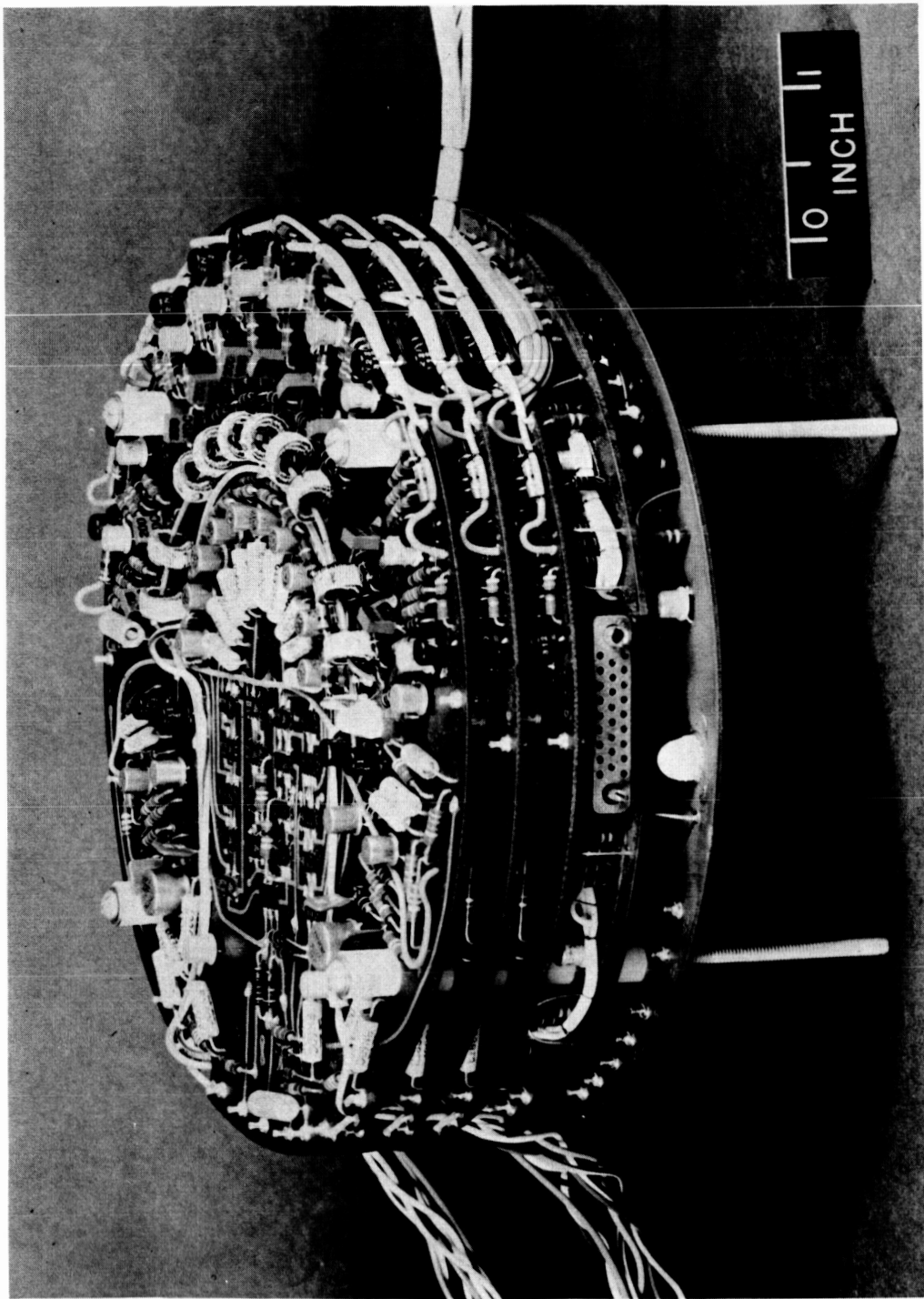


Figure 6.- Temperature detector.



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Figure 7.- Time register and programmer.



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Figure 8.- Complete system before potting.

10#

at a slow rate. The average standby and operating power of the memory is 65 mw.

After recovery from the ocean, the trans-fluxer memory is interrogated by a ground readout system. This system drives the required "prime" and "read" currents sequentially through 30 word lines threading the minor apertures. Twelve sense amplifiers, one for each bit, present the data in parallel form. This particular memory readout scheme was chosen because it ensures the best possible signal-to-noise ratio.

#### Temperature Detector Design

The temperature detector circuit is based on the Wheatstone Bridge principle as shown in figure 6. The thermistor is used as one lower leg of the bridge while one of five precision resistors is switched by means of a transistor having a low offset voltage into the other lower leg. The two upper legs are equal in resistance. A saturating differential amplifier detects when the bridge passes through a null.

Initially, the logic causes Q1 to conduct switching R1 into the bridge. Q2, Q3, Q4, and Q5 are cut off. At this time the thermistor is assumed to have a higher resistance than R1 causing the bridge to be unbalanced. As the thermistor temperature increases, its resistance decreases until finally it becomes lower than R1, and the bridge passes through null. At this time the logic sends a pulse to the memory indicating that the first temperature of interest has been reached, removes drive from Q1, and switches R2 into the bridge by means of Q2. As soon as transients have ceased the bridge is once again unbalanced since R2 is now less than the thermistor resistance. The process repeats itself each time a null is achieved.

#### Safeguards Against Data Destruction

A large part of the system design effort was devoted to insuring a minimum probability that any valid data would be lost either through circuit malfunction subsequent to reentry, handling, or human error. The incorporated safety features include:

1. A nonvolatile, nondestructive readout memory element is employed.
2. No circuitry capable of clearing the memory is included within the payload.
3. The memory write and read functions are completely isolated. Power need not be applied to the memory write circuitry after recovery.
4. The memory word current drivers employ square loop cores with no internal reset capability. Thus the danger of rewriting a word is minimized.
5. Each temperature detector logic circuit assumes a stable condition after the highest

temperature has been reached. Shorting or opening the thermistors subsequently has no effect on the logic.

6. The time register locks in the all zero state after reentry.

7. All power to the memory current drivers is removed after reentry.

#### Construction

The entire system excluding batteries is packaged in a cylindrical container  $2\frac{3}{8}$  inches high by  $6\frac{3}{8}$  inches in diameter. The weight

including potting material is less than  $2\frac{1}{2}$  pounds.

This small volume and weight are achieved for the most part by the use of Texas Instruments Series 51 integrated circuit modules for all logic functions. A total of 88 units are employed in the clock, time register, programmer, and temperature detector circuit. The logic modules are soldered to 1/32-inch-thick epoxy-glass printed circuit boards. Figure 7 gives an example of this type of construction.

The remaining circuits are all constructed using standard printed circuit board techniques. Great care was taken, however, to choose transistors packaged in TO-18 cases instead of TO-5 cases and to use a minimum of components consistent with good design practice. Figure 8 is a photograph of the entire unit prior to potting. The plug visible on one side connects to the memory readout equipment. Other plugs on the bottom connect to the batteries, sensors, and umbilical.

#### Performance

A prototype data storage system has been constructed and qualification begun. Satisfactory performance has been obtained over an ambient temperature range of 0° C to plus 90° C simultaneous with power supply variations of plus or minus 15 percent. It is anticipated that after potting, the unit will operate during shocks as high as 200g and vibration levels encountered during Scout launch. The total power required is 900 mw.

The worst case error of the recorded times of temperature events is plus or minus 40 ms. Half of this is due to time quantization error and half to frequency drift of the clock. The worst case error in detecting a given static temperature level is plus or minus 1° C for temperatures between 50° C and 200° C. At 260° C the error is plus or minus 3° C. Tests are currently being planned to determine overall system dynamic accuracy. It is anticipated that flight of the finished unit on a Scout vehicle will occur in late 1964.

11/4

### Conclusion

The system just described employs an unusual combination of memory techniques, digital circuitry, and analog circuitry to meet the rigid specifications imposed on reentry instrumentation. Its salient characteristics are:

1. No transmitter is required, and hence the radio blackout problem is avoided regardless of the vehicle reentry velocity.
2. The system is lightweight and rugged.
3. The nondestructive readout memory retains information indefinitely with a minimum probability of accidental destruction of the data.